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Reaction-Compensation Technology for Microgravity Laboratory Robots

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Technology development is required to bring the disturbance regions below the required level.

REACTION-COMPENSATION TECHNOLOGY

MULTI-DEGREE-OF-FREEDOM TEST BED

A multi-degree-of-freedom (DOF) manipulator test bed, shown in figure 2, has been constructed to experimentally evaluate and verify the technologies developed under this project. Brush [4] describes the selection of the system's components, shown schematically in figure 3. The 4-DOF robotic arm is driven by roller-traction differentials which are expected to cause insignificant vibration and backlash. A computer is employed for closed-loop arm control and acquisition of joint performance and reaction force and moment data. The base reaction force/moment transducer provides a digital output of the six force and moment components.

ROLLER DRIVEN JOINTS

Roller, or traction, driven actuators provide significant benefits to servomechanism applications in space by offering: zero backlash, high torsional stiffness, low starting friction, low torque ripple, potential for nonlubricated operation (due to low sliding), and over-torque protection (ability to slip at predetermined traction limits). These characteristics, as discussed by Loewenthal, et. al. [5] are important for smooth, controlled robot joints.

Under a NASA program to evaluate and mature advanced telerobotic technologies, Kuban and Williams [6] designed a manipulator arm for a Laboratory Telerobotic Manipulator (LTM) which incorporated a 2-DOF roller-driven joint. To simplify the control system and provide the necessary fineness of control, drive system backlash had to be eliminated. These requirements, plus the need to consider operation in a vacuum were factors contributing to the selection of roller driven joints. The rollers were hardened steel with ion-gold plating to allow dry operation.

This joint design was incorporated into the test bed at NASA-Lewis to demonstrate the servomechanism characteristics of roller-driven robot joints, as well as to verify the reaction-compensating trajectory optimization strategies discussed in the next section.

JOINT TRAJECTORY PLANNING

Dynamics and controls technologies have been utilized to limit the reactions transmitted by a robot through its base to the orbiting laboratory. Several methods for momentum compensation were proposed by Quinn and Lawrence [9]. The basis for the reaction minimization strategy used in this project is joint trajectory planning through the use of redundant DOFs. Manipulators used in space applications may have kinematic redundancy in order to facilitate the performance of tasks. In certain applications, the redundant degrees of freedom may also be used to minimize base reactions.

In deSilva, Chung, and Lawrence [8] a method was developed for trajectory design which employs kinematic redundancy (extra degrees of freedom) for base reaction minimization. The method involves moving the extra sections of the manipulator in a direction inertially opposite to the movement of the end-effector to minimize the base reactions. The procedure employs an optimization strategy for identifying the joint motion solution set which minimizes the resulting base reactions.

Chung and Desa [9] assessed the effect of various weighting functions on the base forces and moments. From these results it was determined that a suitable weighting matrix could be constructed by using average values of base moments and forces. This weighting function can also be tailored to minimize a partial set of reaction components, such as only the forces or only the moments.

Quinn, et.al [10] also incorporated the strategy into a general computer program to simulate and control manipulators with any number of links, joints, and degrees of redundancy. It was found that it is possible to design manipulators through the proper selection of redundancy which will be capable of operating with minimal base reactions. As shown in figure 3, an arbitrary planar manipulator, with two redundant joints, can even exhibit zero net base reaction. In most cases, it is not possible to completely eliminate

base reactions. However, use of these techniques can be employed to lower robotic disturbances to below desired laboratory levels.

Further, Chung and Desa [11] showed that it is possible to eliminate the base reaction function peaks in figure 3 through use of an integral approach. Rather than attempting to minimize the reaction function at every time step, as done in the previously discussed strategy, the integral method seeks to minimize the area under the reaction function curve.

REACTION COMPENSATION EXPERIMENTS

Implementation of the above control strategies on the multi-DOF test bed begins with generating a set of joint angles as a function of time for the desired robot-end motion from the output of the optimization code. This set-point file is downloaded to the control computer. The manipulator is then commanded through the motion in robotic-control, position-feedback mode, while six-axis reaction and joint angle data are acquired. Static, gravity-induced moment loads are removed from the data by subtracting a non-linear function of joint angles based on known physical dimensions and the measured joint angles.

Since the test bed has only a 4-DOF arm, the possible end-effector positions and orientations as well as available redundancies and corresponding joint trajectories are limited. Thus, the theoretically possible improvement from arbitrary to optimized may be relatively small. However the data is expected to verify the trajectory design strategy, which is applicable to robots with any number of DOFs.

Currently efforts are underway to complete the laboratory measurements and compare the data to dynamic model predictions for arbitrary and optimized moves. Other tasks will include measurement of end-effector acceleration and vibration to help address the problem of precise motion, and to evaluate the roller-driven joint concept.

SUMMARY

The goal of the microgravity robotics technology program at NASA Lewis Research Center is to develop reaction-control technology for use in robots for microgravity laboratories. Roller drive design, analysis, and experimentation are underway to provide smooth robot drive systems under a variety of environmental and dynamic conditions. Optimization schemes have been developed which can control reactions in a redundant-joint robot. These and future results will help prevent excessive disturbances to the on-orbit microgravity environment of future space laboratories.

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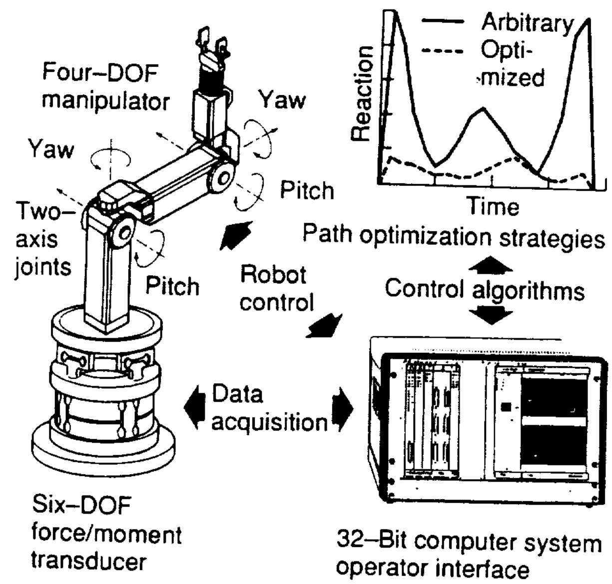

Figure 2.— Microgravity manipulation demonstration test bed [4].

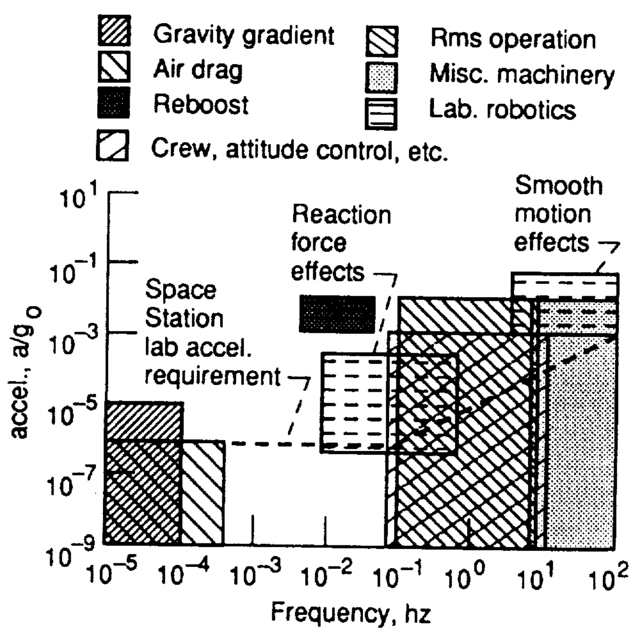

Figure 1.— Potential disturbances to the Space Station Freedom's low gravity environment.

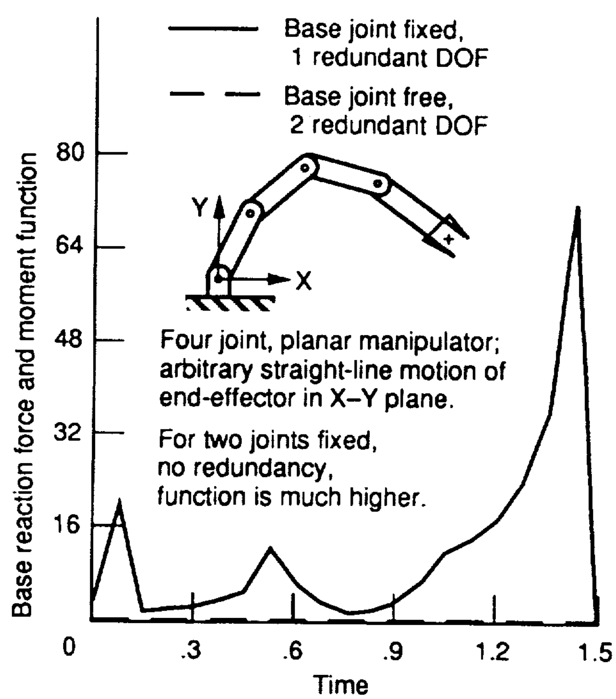

Figure 3. — Typical optimization of base reactions for Four-Joint Planar Manipulator over arbitrary trajectory, with one and two redundancies. Base reaction function is defined as a weighted sum of the squares of reaction forces and moments [10].

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16. Abstract

Robots operating in the microgravity environment of an orbiting laboratory should be capable of manipulating payloads such that the motion of the robot does not disturb adjacent experiments. The current results of a NASA Lewis Research Center technology program to develop smooth, reaction-compensated manipulation based on both mechanism technology and trajectory planning strategies are presented. Experimental validation of methods to reduce robot base reactions through the use of redundant degrees of freedom is discussed. Merits of smooth operation roller-driven robot joints for microgravity manipulators are also reviewed.

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